ENGINEERING GEOLOGY CONSIDERATIONS FOR SPECIFYING DAM FOUNDATION OBJECTIVES

William A. Fraser
Chief, Geology Branch
Division of Safety of Dams
California Department of Water Resources
wfraser@water.ca.gov

January 26, 2001

ABSTRACT

In dam construction, the actual depth to adequate foundation materials at a site is known with certainty only at the points of exploration. The foundation objective serves as a descriptive tool to convey design intent information to construction engineering staff and the contractor. The selection of the most effective approach, or approaches, usually depends on site geology and the amount of available geologic and geotechnical data developed by the site investigation. The engineering geologist should be aware of the relevant approaches for defining a foundation objective prior to the initial site reconnaissance, so the subsurface site investigation can be designed to yield sufficient and meaningful information. This paper summarizes the various ways in which a foundation objective can be described.

INTRODUCTION

Dam foundation requirements are based on the type of dam proposed and is largely dependent on the strength, deformation, and permeability characteristics of site materials. To determine the depth of excavation needed to achieve an adequate foundation, observation of site conditions in borings and test pits, field testing of soil and rock, laboratory testing of representative samples and, ultimately, design analysis is needed. A discussion of site investigation techniques and the influence of geology on dam design and construction are beyond the scope of this paper. For a discussion of site investigation techniques refer to Krynine and Judd (1957), Lowe and Zaccheo (1975), Hunt (1984), and USBR (1987). Discussions of the influence of geology on dams are found in Burnwell and Moneymaker (1950), Legget (1962), Best (1984), Janson (1988), and

Goodman (1993). Janson (1983) provides a summary of the kinds of geologically related problems dams experience, as well as case histories of known dam failures.

This paper discusses various approaches for specifying a foundation objective. The foundation objective is a descriptive tool used to convey design intent information to both construction engineering staff and the contractor. The California Division of Safety of Dams generally requires the specification of a foundation objective for new dam projects. This paper illustrates the importance of engineering geology in developing a foundation objective that will be effective in controlling a dam foundation excavation. The various approaches have been utilized in dam construction practice observed by the author over the past 13 years. A number of recent Northern California dam projects, constructed under DSOD supervision, are presented to illustrate the importance of engineering geology in selecting an appropriate foundation objective approach.

THE FOUNDATION OBJECTIVE

Even at well-explored sites, the depth to adequate foundation materials is known with certainty only at the locations where exploration was actually performed. Foundation excavations must be responsive to unexpected, inadequate conditions. To assist construction engineering staff, the specifications should contain a foundation objective; that is, a description of geologic or geotechnical conditions that meet foundation performance requirements. Other important foundation design details, such as shaping requirements and foundation treatment methods and expectations, are usually specified along with the foundation objective.

Contractors rely on the plans and specifications to determine the volume of excavation required and to select appropriate equipment for the excavation. Explicit direction to a contractor reduces the contractor’s risk, and, therefore, more competitive bidding is possible. To provide a basis for contractor operations, an excavation contour map or other estimate of the expected occurrence of adequate conditions is often included in the plans and specifications. The contractor should be made aware that this is an estimate and that the final excavation must be based on the actual conditions encountered.

As a practical matter, the foundation objective must be recognizable in the foundation excavation. The selection of a particular descriptive approach is highly dependent on site geology as well as on the amount of geologic and geotechnical data developed by the site investigation. For the purposes of this discussion, geologic foundation materials are divided into four general categories: crystalline (intrusive and metamorphic) rock, cemented stratified (sedimentary and volcanic) rock, uncemented stratified (sedimentary and some pyroclastic) rock, and unconsolidated (sedimentary) deposits. Because of this dependence on site geology, the engineering geologist plays an essential role in developing the foundation objective. The engineering geologist should consider possible approaches during the initial site reconnaissance, so the detailed site investigation can be tailored to yield appropriate design information.

APPROACHES FOR SPECIFYING FOUNDATION OBJECTIVES

Listed below are seven ways or approaches for specifying a foundation objective. The geologic and geotechnical observations needed for each approach, and the geologic environment for which each approach may be most applicable, are discussed. Examples of the foundation objectives used in the construction of several recent California dam projects are given.

1. Attain a specific geologic unit

An example of this approach is a narrative goal such as *"extend the cutoff trench excavation completely through the alluvium and three feet into the underlying granitic rock."* This approach requires that sufficient exploration has been performed to identify a continuous geologic unit judged to possess adequate properties for the foundation. The foundation objective is usually described in the specifications, although an excavation contour map plan sheet could be provided based on known occurrences of the specified geologic unit. Typical applications for this approach are dam and appurtenant structure excavations at sites with clearly contrasting materials types such as unconsolidated deposits overlying crystalline rock, stratified cemented rock, and stratified uncemented rock.

This approach was utilized at the 36-foot high Hardester North Dam, near Pope Valley, California, built in

1999. As can be seen in Figure 1, all colluvium was removed to provide a relatively impermeable severely weathered rock foundation for the cutoff trench. In the shell foundation, an unacceptably weak serpentinite-derived black colluvium unit was removed and the embankment fill was placed on the underlying brown clay colluvium, determined by design-level evaluation to be acceptable.

Figure 1. The cutoff trench excavation at Hardester North Dam encounters Great Valley Sequence shale (sh). Embankment fill has been placed downstream of cutoff trench on a stiff to very stiff brown gravelly clay colluvium (Qc2) foundation. The black serpentinite-derived colluvium (Qc1) still visible upstream of the cutoff trench in the reservoir area was removed from dam foundation. [file photo by author]

2. Excavate to a grade based on field testing results

Two examples of this approach are the quantitative statements *"excavate the shell foundation to an elevation that encounters dense silty sand with an SPT* $N_{1(60)}$ *value of 30 blows per foot,"* and *"excavate the cutoff trench to an elevation that encounters crystalline rock with a low permeability of less than 10 lugeons."* This approach is typically used at well-explored sites where a sufficient data set exists to identify the materials with stated properties across the site. Specific geotechnical properties of acceptable foundation materials are stated explicitly and quantified, so the approach is often used for sites where the properties of a given foundation material need to be closely characterized. Field testing could include Standard penetration tests, water tests, and seismic velocity measurements. Because of the repetitive measurements, the inferred target grade can be described as a well-constrained excavation contour map in contract documents. Typical applications are dam and appurtenant structure excavations in unconsolidated deposits, cemented and uncemented stratified rock, and crystalline rock.

This approach was used at the 285-foot high West Dam of the Diamond Valley Reservoir near Hemet, California completed in 2000. The three alluvial channels, which underlie a portion of the West Dam, were excavated to an elevation that removed alluvium with a SPT $N_{1(60)}$ value of less than 30.

3. Attain a specific rock quality

An example of this approach would be the narrative objective to *“excavate the dam foundation to slightly weathered granitic rock.”* Qualities of rock that are potentially significant to dam construction include degree of rock weathering and the density, orientation, aperture, and infilling of the discontinuities. Strength, deformation, and permeability characteristics that are associated with a given rock quality are either measured or assumed, and those characteristics are evaluated for adequacy. Excavation to a given rock quality provides a foundation with those characteristics judged adequate. This approach requires that sufficient exploration be performed to identify the consistent presence of the rock quality specified and reason to believe that rock with similar properties underlies the chosen surface. This approach requires that all observers recognize rock quality and are conversant with descriptive standards. Published rock descriptive standards are available in GSA (1980) and USBR (1990). It should be confirmed during construction that the characteristics assumed to represent a given rock quality are, in fact, appropriate. Typical applications of this approach are dams and appurtenant structure excavations in crystalline and cemented stratified bedrock.

This approach was used at the 200-foot high Los Vaqueros Dam, near Byron, California, built in 1998. The foundation objective for the dam was specified as moderately weathered or better rock. Figure 2 shows the channel section at final grade and left abutment excavation nearing the foundation objective.

Figure 2. Channel section and left abutment of Los Vaqueros Dam. The foundation objective of moderately weathered or better rock of the Panoche Formation has been reached in the channel section and the cutoff wall is completed and the curtain grouting is underway. Additional excavation was needed on the left abutment to obtain an acceptable foundation. [File photo by author]

This approach can be more rigorous, essentially becoming somewhat of a hybrid of approach 2. A more rigorous qualitative assessment was done at the McKays Point Diversion Dam, a 233-foot high arch dam built in 1988, on the North Fork of the Stanislaus River in Calaveras County. The foundation objective for this highly loaded foundation was defined as a minimum of class III rock as defined by Bieniawski (1973). The Bieniawski rock-mass classification system evaluates, by assigning a rock quality rating, both the intact rock and the discontinuities within the rock mass as determined from core samples. Foundation materials judged to possess acceptable deformation properties can be identified in each boring. A foundation excavation contour map estimating the excavation needed to reach acceptable foundation materials can be included in the contract drawings. Figure 3 shows the slightly weathered to fresh, massive rock encountered in the right abutment foundation excavation.

Figure 3. The right abutment of the McKays Point Diversion Dam. In this area the dam is founded on massive, slightly weathered granitic rock. [File photo by author]

4. Achieve a surface that meets a construction control test

Two examples of this approach are *"excavate to a surface with a relative compaction of 95% ASTM D-1557,"* and *"excavate to a surface with an in-place dry density of 120 pounds per cubic foot."* This approach is often used for poorly explored sites where prejudgments cannot be made with confidence. Estimates of the excavation needed to achieve adequate foundation material can be poorly constrained, potentially increasing excavation costs. It requires an ability to physically test the foundation materials during construction, and a belief that materials with adequate properties will underlie the chosen surface.

This approach can also serve as a confirmatory evaluation, especially if the exploration suggests variable or complex geologic conditions. Typical applications are dam and stability berm excavations in unconsolidated deposits.

This approach was used at the Bottoms Dam, a 47-foot high earth dam built in 1989, near Middletown, California. As can be seen in Figure 4, five to seven feet of older alluvium has been left-in-place beneath the shells of the dam. To be considered acceptable for shell foundation, the older alluvium needed to have a density equal to the equivalent maximum dry density (100%) as determined using the ASTM D698-70 compaction standard. The older alluvium was found to meet that standard and was approved for shell foundation.

Figure 4. Cutoff trench excavation for Bottoms Dam is taken several feet into Great Valley Sequence siltstone and shale (s/sh). Five to seven feet of the overlying older alluvium (Qal) was found to be adequate for the upstream and downstream shell foundations. A serpentinite body (sp) was encountered on the knoll beyond the cutoff excavation. [File photo by author]

5. Excavate to a surface based on the ability of excavation equipment

An example of this approach is *“excavate to blade refusal of a Caterpillar D-10N tractor dozer.”* This approach usually requires a calibration test between the capability of the equipment, the character of the material on which it refuses, and adequacy of that material for foundation. An example of an effective calibration demonstration, developed for the Diamond Valley Reservoir, is found in MWD (1995). Confirmation that the desired material has been actually encountered in the excavation is especially important because equipment refusal can occur on unrecognized unsuitable materials. Typical applications include dam and appurtenant structure excavations in weathered crystalline rock. This approach is not appropriate for stratified rock, where weaker materials underlie a stronger layer.

This approach was use for the three dams at Diamond Valley Reservoir, where ripper refusal and blade refusal of specific excavators were specified as the foundation objectives for cutoff trenches and shell foundations, respectively.

6. Excavate to a depth indicated by design analysis

This approach is often used when exploration indicates there is no expectation of material improvement within conventional excavation depth. The adequacy of the foundation is based on engineering analysis in conjunction with design solutions that mitigate the impact of the undesirable foundation materials. A common application of this approach is for low dams on weak alluvial foundations, where the foundation is taken to a specific depth, for example, a depth equal to twice the height of the dam. The foundation objective can be very clearly described in the plans as an excavation contour map. Although conventionally acceptable geologic materials may not be attained, this approach does require confirmation that the geologic conditions exposed in the foundation are consistent with the assumptions made in the justifying design analysis. Differing conditions that invalidate the analysis and, therefore, the finding of adequacy, need to be recognized and evaluated prior to foundation acceptance. Typical applications are dam and appurtenant structure excavations in deep unconsolidated deposits.

7. Achieve a material judged adequate based on visual observation

An example of this approach is to *"excavate to a depth directed by the engineer."* This approach requires the ability to make observations and judgments of strength and permeability during construction, and an expectation that adequate materials underlie the surface chosen. This approach is generally not used as the primary method of identifying adequate dam foundation materials, but should always be specified to confirm the adequacy of any surface indicated by other approaches, and to deal with unexpected foundation materials. Pocket penetrometers, geology hammers, or other hand probes can be used to calibrate and support judgments, but for critical judgments, a construction control test contingency should be incorporated in the specifications. Without an exploratory basis for estimating the depth to adequate foundation materials, it would be difficult for a contractor to bid the work, which could result in higher excavation costs. Typical applications include dam and appurtenant structure excavations at poorly explored, highly variable, or ambiguously characterized sites.

This approach was used to evaluate an unexpected occurrence of lake deposits exposed in the foundation for the 1996 enlargement of the Homestake Tailings Dam in Lake County, California. As seen in Figure 5, the Pleistocene silty lake deposit was encountered over a 200-foot reach of the dam foundation. Since the foundation objective specified was a highly weathered rock, the lake deposit did not meet that objective. Based on visual examination during construction, the dense silt deposit was judged to be an adequate foundation material.

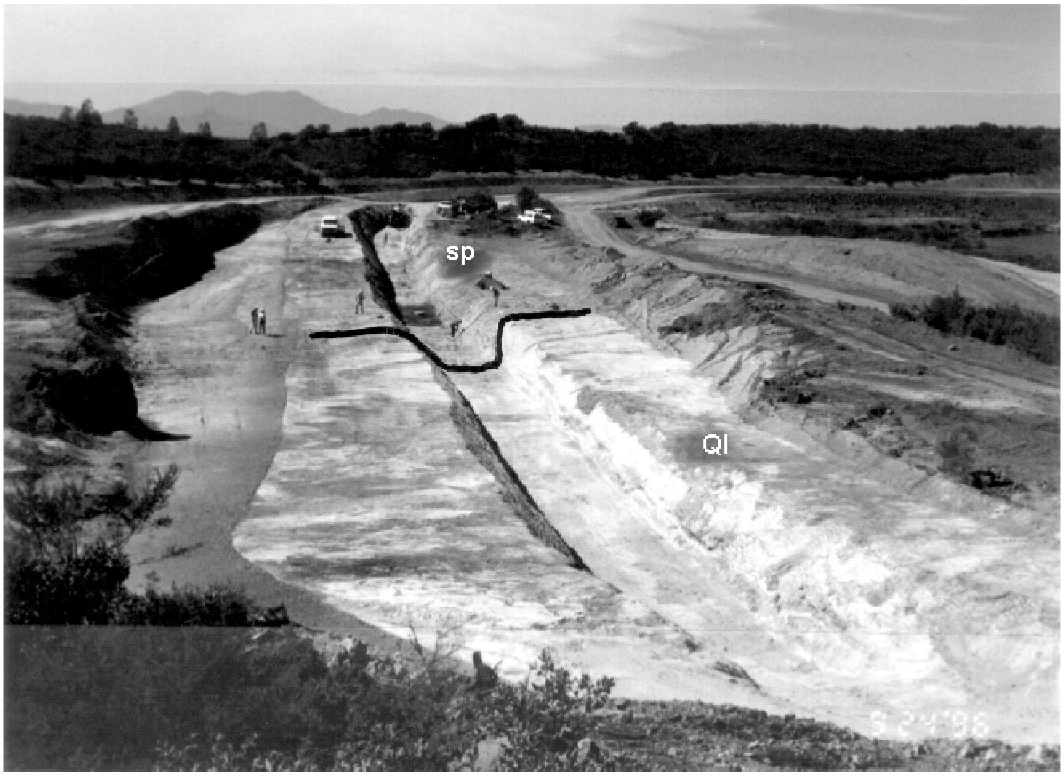

Figure 5. The excavation for the enlargement of Homestake Tailings Dam encountered an unexpected occurrence of Quaternary lake deposits (Ql). Since the foundation objective called for highly weathered serpentinite (sp) rock, the unconsolidated silty deposits required visual examination to determine their adequacy. The fault contact between the serpentinite and the lake deposits was demonstrated to be inactive before fill placement could begin. [file photo by author]

CONCLUSION

The foundation objective is a descriptive tool used to convey information regarding the design intent of a dam foundation to construction inspection staff and the contractor. Separate foundation objectives are usually needed to convey specific requirements for the various features of the project, such as the cutoff trench excavation, shell foundation excavations, outlet excavation, and spillway excavation. More than one approach may be needed to adequately describe some foundation surfaces.

The selection of the most appropriate approach or approaches is based largely on site geology, the amount of available geologic and geotechnical information, as well as the performance requirements of the foundation. The engineering geologist and design engineer should work together while planning the site investigation to identify the most effective approach for specifying a foundation objective at a given site. In this way, sufficient information can be gathered to estimate excavation requirements, while providing a framework to allow the excavation be responsive to any unexpected geologic conditions.

Achieving the foundation objective indicates that a foundation with properties judged adequate, based on design information, has been obtained. The ultimate adequacy of the foundation must be confirmed, as part of final foundation acceptance, to insure the foundation will perform as expected.

REFERENCES

Best, E., 1984, Dams, engineering geology: *in* Finkl, C. W., (ed.), The encyclopedia of applied geology, Van Nostrand Reinhold Company, (New York, New York), 644 p.

Bieniawski, Z.T., 1973, Engineering classification of jointed rock masses: Transactions South African Institute Civil Engineers, v. 15, p. 335-344.

Burwell, E.B., and Moneymaker, B.C., 1950, Geology in dam construction: *in* Paige, S., (ed.), Applications of geology to engineering practice, Berkey Volume, Geological Society of America, New York, 327 p.

GSA (Geological Society of America), 1980, Rock weathering classification: GSA Engineering Geology Division, Data Sheet 1, [Boulder, Colorado].

Goodman, R.E., 1993, Engineering geology-Rock in engineering construction: John Wiley & Sons, Inc., (New York, New York), 412 p.

Hunt, R.E., 1984, Geotechnical engineering investigation manual: McGraw-Hill Book Company, (New York, New York), 983 p.

Janson, R.B., 1983, Dams and public safety: U. S. Bureau of Reclamation, Water Resources Technical Publication, (Denver, Colorado), 332 p.

Janson, R.B., (ed.), 1988, Advanced dam engineering for design, construction, and rehabilitation: Van Nostrand Reinhold, (New York, New York), 811 p.

Krynine, D.P., and Judd, W.R., 1957, Principles of engineering geology and geotechnics: McGraw-Hill Book Company, (New York, New York), 730 p.

Legget, R.F., 1962, Geology and engineering: McGraw-Hill Book Company, (New York, New York), 884 p.

Lowe, J., and Zaccheo, P.F., 1975, Subsurface explorations and sampling: *in* Winterkorn, H.F., and Fang, H.Y., (eds.), Foundation engineering handbook, Van Nostrand Reinhold Company, (New York, New York), 751 p.

MWD (Metropolitan Water District of Southern California), 1995, Test Excavation TE-1, Appendix C-3 *of* Domenigoni Valley Reservoir Project, East Dam Geotechnical Report: Metropolitan Water District, [Los Angeles, California], 5 p.

USBR (U. S. Bureau of Reclamation), 1990, Engineering geology field manual: U. S. Bureau of Reclamation (Denver, Colorado), 598 p. [This manual does not have a publication date printed in it, and USBR does not recognize a formal date of publication]

USBR (U. S. Bureau of Reclamation), 1987, Design of small dams: U. S. Bureau of Reclamation, Water Resources Technical Publication, (Denver, Colorado), 860 p.